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Regional body composition changes in women after 6 months of periodized physical training

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[1]*Laboratory for Sports Medicine, Intercollege Program in Physiology, Department of Kinesiology, The Pennsylvania State University, University Park, Pennsylvania 16802;* [2]*Military Performance Division, United States Army Research Institute of Environmental Medicine, Natick, Massachusetts 01760; and* [3]*Human Performance Laboratory, Ball State University, Muncie, Indiana 47306*

Nindl, Bradley C., Everett A. Harman, James O. Marx, Lincoln A. Gotshalk, Peter N. Frykman, Eric Lammi, Chris Palmer, and William J. Kraemer. Regional body composition changes in women after 6 months of periodized physical training. *J Appl Physiol* 88: 2251–2259, 2000.—Data are lacking regarding regional morphological changes among women after prolonged physical training. This study employed dual-energy X-ray absorptiometry to assess changes in whole body and regional (i.e., trunk, legs, arms) fat mass, lean mass, and bone mineral content body composition adaptations in 31 healthy women pre-, mid-, and post-6 mo of periodized physical training. These results were compared with those of *1*) a control group of women who had not undergone the training program and were assessed pre- and post-6 mo and *2*) a group of 18 men that was tested only once. Additionally, magnetic resonance imaging was used to assess changes in muscle morphology of the thigh in a subset of 11 members of the training group. Physical training consisted of a combination of aerobic and resistance exercise in which the subjects engaged for 5 days/wk for 24 wk. Overall, the training group experienced a 2.2% decrease, a 10% decrease, and a 2.2% increase for body mass, fat mass, and soft tissue lean mass, respectively. No changes in bone mineral content were detected. The women had less of their soft tissue lean mass distributed in their arms than did the men, both before and after the women were trained. Novel to this study were the striking differences in the responses in the tissue composition of the arms (31% loss in fat mass but no change in lean mass) compared with the legs (5.5% gain in lean mass but no change in fat mass). There was a 12% fat loss in the trunk with no change in soft tissue lean mass. Dual-energy X-ray absorptiometry and magnetic resonance imaging fat mass measurements showed good agreement (r = 0.72–0.92); their lean mass measurements were similar as well, showing ~5.5% increases in leg lean tissue. These findings show the importance of considering regional body composition changes, rather than whole body changes alone when assessing the effects of a periodized physical training program.

dual-energy X-ray absorptiometry; magnetic resonance imaging; resistance training; body fat

IN COMPARISON TO MEN, the available data on the physiological changes in women after prolonged (i.e., >2 mo) periodized resistance training are scant (25, 27). Although prior research has demonstrated that resistance training in women can augment strength, physical performance, fat-free mass, and muscle fiber hypertrophy (3, 4, 8, 26), information is lacking regarding regional (i.e., upper body vs. lower body) changes in soft tissue composition (i.e., fat and lean mass).

It has generally been regarded that for women to exhibit muscular hypertrophy, longer adaptation periods are required (i.e., >2 mo) than for men. The advent of sophisticated measurement techniques to assess segmental tissue composition [e.g., dual-energy X-ray absorptiometry (DEXA) and magnetic resonance imaging (MRI)] now allows for accurate assessment of longitudinal changes in limb morphology (2, 6, 12, 22). Nindl et al. (14, 15) reported DEXA-assessed longitudinal changes in regional fat mass (i.e., arm, trunk, and leg) in young men after an intensive military training course (i.e., US Army Ranger training). However, there is a paucity of data concerning longitudinal changes for either fat or lean mass after resistance training in women as assessed by either DEXA or MRI. A recent study by Chilibeck et al. (4) utilized DEXA technology to track hypertrophy in women for the arms, trunk, and legs after a 10-wk resistance training program. Their data showed that hypertrophy of the legs and trunk lagged behind that of the arms. This study did not, however, report the changes in regional fat mass. An understanding of how regional fat mass is altered with training is also important, because location of fat deposition is more closely related to cardiovascular health risk than is total fat mass (18).

Physical training programs that include both resistance and aerobic modes of exercise are known to elicit alterations in whole body lean and fat mass. Increased lean mass and decreased fat mass are favorable adaptations that correspond to improved health and fitness. Less is known concerning regional variation in women in response to training. Regional differences in lipolytic activity in women are known to exist (e.g., the lipolytic response to exercise is more pronounced in abdominal than in peripheral tissue) (9, 21). Whether regional muscle tissue also exhibits a degree of heterogeneity in women in response to training is not known. It has been reported that men have proportionally more of their muscle mass distributed to the upper body than do

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women, which has been proposed as a partial explanation for the difference in upper body strength between the genders. For example, Miller et al. (13) reported that the cross-sectional areas (CSAs) of the women's biceps brachii, elbow flexors, vastus lateralis, and knee extensors were 55, 59, 70, and 75% those of men, respectively. In light of that study and the findings of Chilibeck et al. (4), that the arms of women underwent greater hypertrophy than did their legs and trunk, one may hypothesize that with resistance training, women may alter their relative muscle mass distribution so that a greater proportion exists in their upper body. To date, no study has concurrently reported arm, trunk, and leg adaptations with respect to soft tissue fat and lean mass changes. Therefore, the primary purpose of the present study was to compare the relative adaptations in fat and lean soft tissue mass of the arms, legs, and trunk in women in response to 24 wk of periodized physical training. Secondary purposes were to compare DEXA estimates of leg tissue composition with MRI estimates of thigh tissue composition in these women and to compare the relative proportion of fat and lean soft tissue in the arms, legs, and trunk in the trained women with that of a group of men who had not undergone the experimental training program.

METHODS

Subjects. Three groups of subjects participated in this study. *1*) Thirty-one women (28 ± 4 yr, 68 ± 12 kg, 164 ± 6 cm) were recruited via newspaper and television publicity from the local area (Boston's western suburbs). After an informational briefing covering all aspects of study methodology and time requirements, subjects were asked to read and sign an informed consent document. This study was approved by the Human Use Review Committee at the US Army Research Institute of Environmental Medicine (Natick, MA) and by the Human Subjects Research Review Board Office of the Medical Research and Materiel Command, which falls under the office of Army Surgeon General. All subjects were given a comprehensive physical examination by a physician to ensure that they were free of any endocrine, orthopedic, or other disorders that would contraindicate a whole body physical training program, and all had received a negative serum pregnancy test. *2*) Five women, whose physical characteristics did not differ from the experimental training group, were randomly recruited, separate from the experimental group, to serve as nonexercise controls. These subjects were required to maintain their normal daily activity levels throughout the 6-mo study. *3*) A group of 18 men (27 ± 6 yr, 82 ± 14 kg, 179 ± 8 cm) served as a static control comparison group.

DEXA. Total body estimates of percent fat, bone mineral density, and body content of bone, fat, and nonbone lean tissue were determined by using manufacturer-supplied algorithms (Total Body Analysis, version 3.6, Lunar, Madison, WI). Precision of this measurement is better than ±0.5% for body fat. For this procedure, the subject dressed in shorts and T-shirt and lay face-up on a DEXA scanner table. The body was carefully positioned so that it was laterally centered on the table with the hands palm downward. Velcro straps were used to keep the knees together and support the feet so that they tilted 45° from the vertical. Scanning was in 1-cm slices from head to toe by using the 20-min scanning speed. Regional measurements (arm, leg, and trunk) were determined on the basis of bony landmarks via manual analysis. Vertical boundaries separated the arms from the body at the shoulder, and angled boundaries separated the legs from the trunk (Fig. 1). Precision of the measurement in these three regions is 1.5, 0.8, and 1.1% for the arms, legs, and trunk, respectively (15). DEXA measurements were obtained before the beginning of the study (pre), after 14 wk of training (mid), and at the conclusion of 24 wk of training (post).

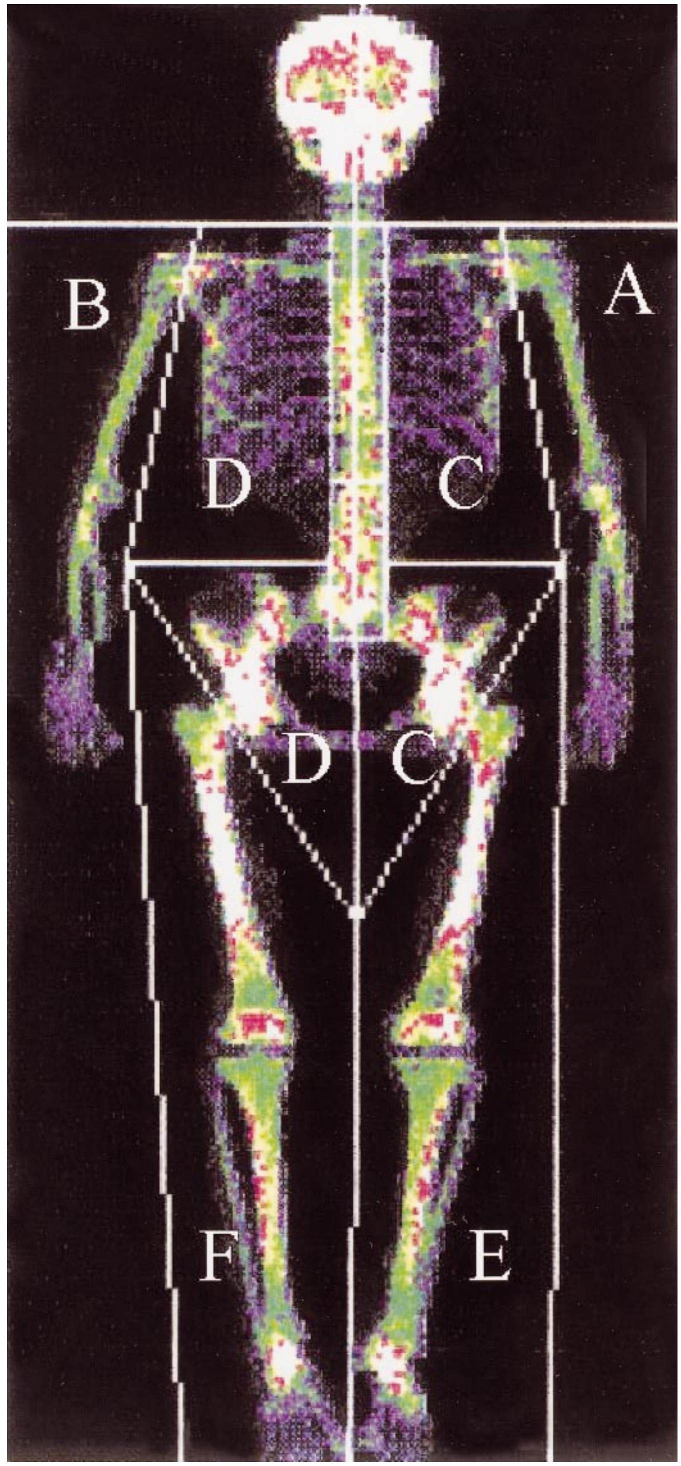

Fig. 1. Dual-energy X-ray absorptiometry scan illustrating cut points for arm, trunk, and leg regions. *A* and *B*, arms. *C*, and *D*, trunk. *E* and F, legs.

MRI. To compare regional changes in the leg/thigh between DEXA and MRI technologies, a random subset of 11 women underwent cross-sectional MRI scans of the midthigh at the MRI facilities at West Suburban Imaging in Wellesley, MA. The CSAs of lean mass, which include lean soft tissue and bone mass, and fat tissue mass were measured pre- and posttraining by MRI using a 1.5-T Picker Vista MR with MR6B software. Images were obtained by alteration of the spin-lattice or longitudinal relaxation time. Weighting of longitudinal relaxation time was with repetition time of 300 ms, echo time 17 ms, radio frequency at 90°, and power absorption of 0.028 W/kg. Analysis of the CSAs was determined from the MRI scan by using a gradient echo technique, which allows the greatest delineation and distinction between muscles and has been shown to be more sensitive than the computed tomography scan for determining muscle size change. Fifteen transaxial images of 1-cm slices were obtained equidistantly between the base of the femoral head and midpatella. The dominant limbs were used for the investigation. For the thigh, *slice 8* was used (*slice 1* being the base of the femoral head). Tissue CSA was obtained by displaying the images through Maxitron displayer and Adobe program and by using the National Institutes of Health 1.55.20A Image Analysis pixel-counting program. Measured CSAs of the thigh included total fat-free mass, fat tissue mass, bone, rectus femoris, vastus lateralis, vastus intermedius, vastus medialis, satorius, biceps femoris short head, biceps femoris long head, semitendinosis, semimembranosis, gracilis, and the adductor group (Fig. 2). CSA (measured in cm^2) was determined by tracing along the border of each muscle. Two hundred initial tracings with the dominant hand were used to establish tracing validity of the investigation according to the methods of Bloomstand et al. (1). The same investigator did all measurements for all subjects and demonstrated a test-retest intraclass reliability of 0.99.

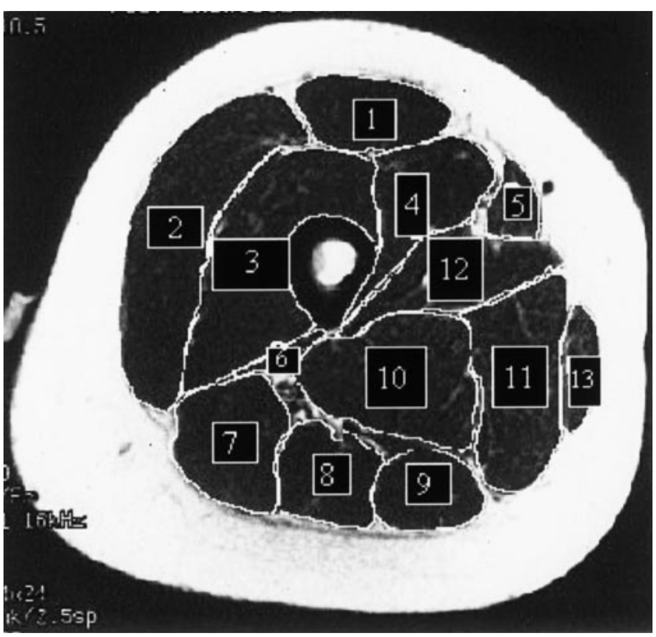

Fig. 2. Thigh muscle cross-sectional area determined via magnetic resonance imaging. Individual muscles have been outlined to display boundaries used in the analysis: *1*, rectus femoris; *2*, vastus lateralis; *3*, vastus intermedius; *4*, vastus medialis; *5*, sartorious; *6*, biceps femoris short head; *7*, biceps femoris long head; *8*, semimembranosis; *9*, semitendinosis; *10*, adductor magnus; *11*, adductor longus; *12*, adductor brevis; *13*, gracilis.

Table 1. *Initial training program*

Day	Exercise	Duration
Monday	Lift weights	50 min, 21 sets
	Rest	10 min
	Run	3.2 km, fast pace
Tuesday	Lift weights	50 min, 21 sets
	Rest	10 min
	Varied drills	0–30 min
Wednesday	Backpack	8 km at minimum of 6.4 km/h pace (maximum load 34 kg)
Thursday	Lift weights	50 min, 21 sets
	Rest	10 min
	Varied drills	0–30 min
Friday	Lift weights	50 min, 21 sets
	Rest	10 min
	Run	3.2 km, fast pace

Physical training regimen. The training was a 24-wk total body, periodized strength and endurance program specially designed to enhance women's performance of military-specific occupational tasks. The changes in physical performance produced in this study have been reported previously (7). The training was 1.5 h/day for 5 days/wk. All training sessions were directly supervised by trained personnel, certified as Strength and Conditioning Specialists by the National Strength and Conditioning Association, who oversaw the entire program, monitored subject progress, and modified the workouts as needed. The initial overall weekly training program is shown in Table 1, and the initial resistance training segment of the program is shown in Table 2.

One can see that the subjects did not perform consecutive sets of an exercise. Rather, they performed exercises in groups of two or three, rotating between the exercises within the group before going on to the next group. An exercise set commenced about every 2 min, translating to ~30 s of exercise and 1.5 min of rest. Because the exercises were performed in groups, there was only 1.5 min of rest between sets of adjacent exercises, but there was 3.5–5.5 min of rest between sets of the same exercise.

Table 2. *Initial resistance training program*

Set No.	Monday and Thursday	Tuesday and Friday
	Exercise	Exercise
1	Squat	Underhand medicine ball toss
2	Bench press	Wide-grip barbell press
3	Squat	Underhand medicine ball toss
4	Bench press	Wide-grip barbell press
5	Squat	Underhand medicine ball toss
6	Bench press	Wide-grip barbell press
7	Squat	Underhand medicine ball toss
8	Bench press	Wide-grip barbell pulldown
9	Squat	Underhand medicine ball toss
10	Bench press	Wide-grip barbell pulldown
11	Squat	Underhand medicine ball toss
12	Bench press	Wide-grip barbell pulldown
13	Back hyperextension	Sit-up
14	Medium-grip barbell press	Leg curl
15	Row with elbows high	Row with elbows low
16	Back hyperextension	Sit-up
17	Medium-grip barbell press	Leg curl
18	Row with elbows high	Row with elbows low
19	Back hyperextension	Sit-up
20	Medium-grip barbell press	Leg curl
21	Row with elbows high	Row with elbows low

Table 3. *Dual-energy X-ray absorptiometry-assessed changes in total soft tissue content over 6 mo of periodized physical training*

Body Region	*Week 0*	*Week 14*	*Week 24*	*Weeks 0–14*	*Weeks 14–24*	*Weeks 0–24*
Total body, kg	66.5 ± 11.8*	65.9 ± 11.1*	64.8 ± 10.9†	−0.6 ± 3.7%	−1.5 ± 2.4%	−2.2 ± 4.4%
Left side, kg	33.4 ± 6.0*	33.1 ± 5.7*†	32.5 ± 5.4†	−0.8 ± 4.5%	−1.4 ± 3.2%	−2.2 ± 5.6%
Right side, kg	33.1 ± 5.8*	32.8 ± 5.5*†	32.3 ± 5.6†	−0.4 ± 3.9%	−1.7 ± 3.0%	−2.1 ± 4.7%
Trunk, kg	31.9 ± 6.2*	31.4 ± 5.5*	30.7 ± 5.7†	−1.1 ± 5.0%	−2.3 ± 4.3%	−3.4 ± 5.8%
Left, kg	16.1 ± 3.3*	15.9 ± 2.9*†	15.6 ± 2.9†	−0.8 ± 6.1%	−1.7 ± 4.7%	−2.5 ± 7.2%
Right, kg	15.8 ± 3.1*	15.5 ± 2.7*	15.1 ± 2.9†	−1.2 ± 5.4%	−2.9 ± 5.5%	−4.1 ± 6.6%
Legs, kg	22.3 ± 4.2*	23.0 ± 4.2†	23.1 ± 4.1†	3.2 ± 5.3%	0.7 ± 3.9%	3.8 ± 5.7%
Left, kg	11.1 ± 2.2*	11.4 ± 2.1†	11.5 ± 2.1†	3.2 ± 6.3%	0.3 ± 3.8%	3.4 ± 6.1%
Right, kg	11.2 ± 2.1*	11.5 ± 2.1†	11.6 ± 2.1†	3.2 ± 5.0%	1.1 ± 4.8%	4.2 ± 6.0%
Arms, kg	8.1 ± 1.9*	7.4 ± 1.7†	7.0 ± 1.4‡	−8.7 ± 9.6%	−3.7 ± 10.3%	−12.4 ± 10.4%
Left, kg	4.0 ± 1.0*	3.6 ± 0.9†	3.4 ± 0.7†	−9.8 ± 10.9%	−4.1 ± 11.1%	−13.8 ± 12.2%
Right, kg	4.1 ± 1.0*	3.8 ± 0.9†	3.6 ± 0.8†	−7.0 ± 11.7	−3.0 ± 12.5%	−10.6 ± 11.0%

Values are means ± SD. Same superscripted symbol across time points denotes lack of statistically significant ($P \leq 0.05$) difference between means of a variable.

Over the 24 wk of training, monthly changes were made to the exercise routine by using a periodized exercise model. In the beginning, the subjects performed 10–12 repetitions per exercise set. As they learned the exercise techniques and became stronger, the number of repetitions was reduced and the weight was increased. After the midpoint of the training program, the repetitions were increased and the weights were reduced. From then until the end of training, the number of repetitions per set was progressively reduced while the weights were increased.

As the training progressed, exercises that were more physically demanding and those requiring more physical coordination were substituted for simpler and less physically demanding ones employing the same body movements.

Statistics. Statistical analysis was performed by Statistica software for the Macintosh (Statsoft; 1984–1994; Tulsa, OK). Descriptive statistics were calculated for all measurements. Homogeneity of variance and normality of distribution were determined for all data by examining the skewness and kurtosis values. An ANOVA with repeated measures was used to determine differences in all dependent variables. There were three levels of the repeated measure (0, 14, and 24 wk). A Tukey's post hoc follow-up test was used when significance was detected. For women-to-men comparisons, an independent *t*-test was employed. Pearson correlation coefficients evaluated the relationship between DEXA and MRI measurements of thigh fat and lean soft tissue mass as well as percent changes after training. An α level of 0.05 was used for all statistics.

RESULTS

Changes in whole body and regional total soft tissue mass over the 24-wk training period are given in Table 3. A significant decrease (1.7 kg; 2.2%) in total body soft tissue content was evidenced. Corresponding with this decline in whole body soft tissue were regional losses in the trunk after 24 wk (1.2 kg; 3.4%) and the arms at 14 and 24 wk (8.7 and 12.4% of the initial value, respectively). The legs, however, underwent a significant increase in total soft tissue content (0.8 kg; 3.8%) after 6 mo of training.

Changes in soft tissue fat and lean mass are shown in Tables 4 and 5, respectively. Of the ~2.6 kg of fat tissue that were lost after training, ~1.3 kg were from the trunk region and ~1.1 kg were from the arm region. Significant losses in fat tissue were observed at both 14 and 24 wk (4.2 and 9.7% of initial values, respectively). The arms exhibited the largest loss on a percent basis (30.8%), followed by the trunk (11.6%). The legs did not experience any changes in tissue fat content throughout the study.

An overall 2.2% increase in whole body soft tissue lean mass (Table 5) was observed after 6 mo of training with a significant increase observed by 14 wk. This increase came mainly from the leg region. Increases in

Table 4. *Dual-energy X-ray absorptiometry-assessed changes in fat tissue content over 6 mo of periodized physical training*

Body Region	*Week 0*	*Week 14*	*Week 24*	*Weeks 0–14*	*Weeks 14–24*	*Weeks 0–24*
Total body, kg	24.7 ± 9.4*	23.4 ± 8.8†	22.1 ± 8.7‡	−4.2 ± 9.2%	−5.8 ± 8.0%	−9.7 ± 12.8%
Left side, kg	12.4 ± 4.8*	11.6 ± 4.4†	11.1 ± 4.3‡	−4.7 ± 9.6%	−5.1 ± 8.0%	−9.8 ± 13.8%
Right side, kg	12.3 ± 4.7*	11.6 ± 4.4†	11.0 ± 4.4‡	−4.2 ± 8.5%	−5.7 ± 8.2%	−9.5 ± 12.5%
Trunk, kg	11.5 ± 4.8*	10.9 ± 4.5†	10.2 ± 4.4‡	−4.9 ± 10.4%	−7.2 ± 12.0%	−11.6 ± 16.8%
Left, kg	5.8 ± 2.4*	5.5 ± 2.3†	5.2 ± 2.2‡	−4.8 ± 11.5%	−6.7 ± 11.8%	−10.9 ± 18.1%
Right, kg	5.7 ± 2.4*	5.4 ± 2.3†	5.0 ± 2.2‡	−4.8 ± 10.4%	−7.6 ± 12.8%	−12.0 ± 16.5%
Legs, kg	8.2 ± 3.2*	8.4 ± 3.2*	8.2 ± 3.1*	3.0 ± 1.8%	−1.5 ± 7.6%	1.4 ± 13.1%
Left, kg	4.1 ± 1.6*	4.2 ± 1.6*	4.1 ± 1.6*	3.5 ± 12.4%	−2.2 ± 7.0%	1.3 ± 13.9%
Right, kg	4.1 ± 1.6*	4.2 ± 1.6*	4.1 ± 1.5*	3.0 ± 11.8%	−1.2 ± 8.7%	1.5 ± 13.3%
Arms, kg	3.5 ± 1.4*	2.8 ± 1.3†	2.4 ± 1.1‡	−21.4 ± 18.2%	−10.7 ± 22.4%	−30.8 ± 28.6%
Left, kg	1.8 ± 0.7*	1.3 ± 0.6†	1.1 ± 0.5‡	−23.6 ± 19.0%	−9.7 ± 25.2%	−27.8 ± 20.9%
Right, kg	1.7 ± 0.7*	1.4 ± 0.7†	1.3 ± 0.6‡	−18.0 ± 20.8%	−10.7 ± 24.1%	−32.4 ± 27.0%

Values are means ± SD. Same superscripted symbol across time points denotes lack of statistically significant ($P \leq 0.05$) difference between means of a variable.

Table 5. *Dual-energy X-ray absorptiometry-assessed changes in lean soft tissue mass over 6 mo of periodized physical training*

Body Region	*Week 0*	*Week 14*	*Week 24*	*Weeks 0–14*	*Weeks 14–24*	*Weeks 0–24*
Total body, kg	41.8 ± 4.6*	42.5 ± 4.3†	42.7 ± 4.2†	1.7 ± 2.6%	0.5 ± 2.1%	2.2 ± 3.1%
Left side, kg	21.0 ± 2.2*	21.3 ± 2.3†	21.4 ± 2.2†	1.5 ± 3.1%	0.7 ± 2.9%	2.2 ± 3.9%
Right side, kg	20.8 ± 1.9*	21.2 ± 2.1†	21.3 ± 2.1†	1.9 ± 3.5%	0.3 ± 3.0%	2.2 ± 4.4%
Trunk, kg	20.3 ± 1.9*	20.5 ± 2.1*	20.5 ± 2.0*	1.1 ± 4.7%	0.0 ± 4.2%	1.0 ± 4.8%
Left, kg	10.3 ± 1.1*	10.4 ± 1.1*	10.4 ± 1.1*	1.4 ± 5.3%	0.7 ± 4.6%	2.0 ± 5.8%
Right, kg	10.1 ± 0.9*	10.1 ± 0.9*	10.1 ± 1.0*	0.9 ± 5.8%	−0.6 ± 5.4%	0.2 ± 6.5%
Legs, kg	14.1 ± 1.8*	14.6 ± 1.8†	14.8 ± 1.9‡	3.8 ± 3.8%	1.8 ± 3.8%	5.5 ± 4.5%
Left, kg	7.0 ± 0.9*	7.3 ± 0.9†	7.4 ± 1.0†	3.4 ± 4.5%	1.5 ± 3.9%	4.8 ± 4.7%
Right, kg	7.1 ± 0.9*	7.3 ± 0.9†	7.5 ± 1.0‡	4.1 ± 4.3%	2.1 ± 4.4%	6.3 ± 5.2%
Arms, kg	4.6 ± 0.7*	4.6 ± 0.7*	4.6 ± 0.6*	0.2 ± 6.9%	0.6 ± 7.0%	0.6 ± 6.6%
Left, kg	2.3 ± 0.4*	2.3 ± 0.3*	2.3 ± 0.3*	−0.9 ± 9.4%	0.3 ± 8.1%	−0.8 ± 9.5%
Right, kg	2.3 ± 0.3*	2.4 ± 0.3*	2.4 ± 0.3*	0.7 ± 8.4%	1.2 ± 8.3%	1.5 ± 7.2%

Values are means ± SD. Same superscripted symbol across time points denotes lack of statistically significant ($P \leq 0.05$) difference between means of a variable.

soft tissue lean mass in the leg region were seen between *weeks 0* and *14* (3.8%) and between *weeks 14* and *24* (1.8%) for an overall increase of 0.7 kg or 5.5%. No significant changes in soft tissue lean mass were apparent for the trunk or arm regions.

No significant changes in whole body or regional bone mineral content were observed in response to the training program (data not shown). Whole body and regional percent fat values are listed in Table 6. Initial total body adiposity was 34.5% and significantly decreased to 33.1% after 14 wk of training and to 31.8% after 6 mo of training. Before training, the arms had the greatest relative adiposity (40.0%), followed by the legs (34.4%) and trunk (33.8%). With the accentuated loss of fat in the arms after only 14 wk of training, the relative regional adiposity of the arms and legs (34.3 vs. 34.1%, respectively) was equivalent and slightly greater than that of the trunk (32.4%). After 6 mo of training, the relative adiposity of the legs (33.4%) was higher than that of the trunk (30.8%) or arms (31.3%).

The body composition of the control group of women (n = 5) remained stable throughout the 6-mo period, because the only significant difference was an increase in tissue mass of the arms (data not shown). Table 7 gives the regional body composition baseline values for women vs. men; all measurements were significantly different between men and women.

Table 6. *Dual-energy X-ray absorptiometry-assessed changes in region percent fat over 6 mo of periodized physical training*

Body Region	*Week 0*	*Week 14*	*Week 24*
Total Body	34.5 ± 7.8*	33.1 ± 7.6†	31.8 ± 7.9‡
Left side	34.6 ± 7.7*	33.1 ± 7.6†	31.8 ± 7.8‡
Right side	34.5 ± 7.9*	33.0 ± 7.6†	31.7 ± 8.7‡
Trunk	33.8 ± 8.3*	32.4 ± 8.3†	30.8 ± 8.6‡
Left	34.0 ± 8.1*	32.5 ± 8.3†	30.9 ± 8.6‡
Right	33.7 ± 8.5*	32.3 ± 8.4†	30.7 ± 8.7‡
Legs	34.4 ± 7.7*	34.1 ± 7.2*	33.4 ± 7.5*
Left	34.3 ± 7.6*	34.2 ± 7.1*	33.5 ± 7.5*
Right	34.4 ± 7.8*	33.9 ± 7.2*†	33.3 ± 7.5†
Arms	40.0 ± 8.4*	34.3 ± 9.4†	31.3 ± 9.5‡
Left	40.3 ± 8.8*	33.9 ± 9.9†	30.8 ± 9.7‡
Right	39.6 ± 8.5*	34.5 ± 9.2†	31.5 ± 9.5‡

Values are means ± SD given in %. Same superscripted symbol across time points denotes lack of statistically significant ($P \leq 0.05$) difference between means of a variable.

Table 8 displays the MRI-assessed CSA changes in thigh morphology. Overall, significant pre-to-post increases were observed in the total thigh CSA (249 ± 14 vs. 258 ± 15 cm^2) and the lean thigh CSA (130 ± 6 vs. 137 ± 6 cm^2). The only individual muscle CSA to exhibit a significant increase after training was the rectus femoris (8.2 ± 0.8 vs. 9.0 ± 0.8 cm^2). Fat CSA was unchanged throughout the training. Table 9 shows the correlation between MRI thigh CSA and DEXA leg estimates of lean and fat tissue. Significant relationships between the DEXA and MRI were observed for pre and post measurements and percent change for both lean and fat tissue.

DISCUSSION

This investigation compared DEXA-assessed whole body and regional (i.e., arms, legs, trunk) tissue composition changes in women during 24 wk of physical training. Overall, a negative energy balance throughout the 24-wk conditioning program was reflected by a significant loss in total body tissue mass (−2.2%). A positive nitrogen balance was indicated by a significant gain in soft tissue lean mass (2.2%), attributed mainly to a gain in soft tissue lean mass of the legs (5.5%). The loss in fat mass and increase in lean mass are favorable and desired effects of exercise training programs and contribute to an enhanced level of fitness and health. Novel to this study are the striking differences in regional tissue composition response of the arms (loss in fat mass ~31% but no change in soft tissue lean mass) and legs (gain in soft tissue lean mass of 5.5% but no change in fat mass). Few studies are available in the literature that have documented concomitant upper body, lower body, and truncal changes in soft tissue fat and lean mass and bone mineral content after longitudinal physical training. The findings of this study show the importance of considering regional body composition changes rather than whole body changes alone.

The training paradigm employed in this study included both resistance and aerobic modes of exercise performed 5 days/wk (i.e., high volume of total work) and was efficacious in decreasing total body adiposity

Table 7. *Comparison of regional body composition between men and women*

Body Region	Total Mass, kg	Lean Mass, kg	Fat Mass, kg	BMC, g	Percent Fat
Women					
Whole body	66.5 ± 11.8	41.8 ± 4.0	24.7 ± 9.4	2.70 ± 0.64	34.5 ± 7.8
Trunk	31.9 ± 5.8	20.3 ± 1.9	11.5 ± 4.8	0.94 ± 0.26	33.8 ± 8.3
Legs	22.3 ± 4.2	14.1 ± 1.8	8.2 ± 3.2	0.95 ± 0.24	34.4 ± 7.7
Arms	8.1 ± 1.9	4.6 ± 0.7	3.5 ± 1.4	0.31 ± 0.08	40.0 ± 8.4
Men					
Whole body	77.6 ± 12.4	62.7 ± 8.9	14.9 ± 5.5	3.51 ± 0.73	18.0 ± 5.0
Trunk	36.5 ± 6.1	29.0 ± 3.7	7.5 ± 3.0	1.12 ± 0.33	19.3 ± 5.3
Legs	26.7 ± 4.4	21.6 ± 3.5	5.1 ± 1.7	1.32 ± 0.36	18.0 ± 5.0
Arms	9.2 ± 1.9	7.8 ± 1.6	1.4 ± 0.7	0.50 ± 0.2	14.2 ± 5.7

Values are means ± SD for 31 women and 18 men. BMC, bone mineral content. All values were significantly different between men and women, $P \leq 0.05$.

and regional adiposity of the truncal and arm regions. Although the leg region contained 8.2 kg of fat tissue, representing 34% of total initial fat stores, no mobilization of fat stores from this region was observed. DEXA and MRI measurements of leg/thigh fat tissue both supported this finding. A prominent resistance of thigh fat to mobilization and utilization has been reported previously in both women and men (19, 21). This resistance to mobilization of femoral adipose tissue has been attributed to a number of possible factors, including lipoprotein lipase activity, local blood flow, receptor agonist-to-antagonist ratio, sympathetic nervous stimulation, tissue morphology, and lipolytic responsiveness to endocrine stimuli (9, 19, 21).

On the basis of data from previous studies (5, 15) that evaluated regional fat loss in male Ranger students after a prolonged energy deficit, we suggested a regional hierarchy of fat mobilization in these men: abdomen/trunk > arms > legs. For the women in this study, the regional hierarchy of fat mobilization was arm > truncal > legs. These two studies did involve separate and unique interventions, but differences in the hierarchy of fat metabolism between genders may also be due to complex interactions between regional adipocyte receptors and sexually dimorphic concentrations of sex steroids (e.g., testosterone and estradiol).

In the previous study, it was demonstrated that those Ranger students with the highest initial total body adiposity lost significantly more fat tissue from the arm region than did those Ranger students with the lowest initial total body adiposity. It is known that the subcutaneous fat of the arm area is morphologically different compared with other areas, and this fact may contribute to a propensity of the arm area to store and mobilize fat. In a cross-sectional study of 100 women aged 18–87 yr, Madsen et al. (11) reported that the regional percentage of fat was greatest in the arm area. In the present study, whereas women had greater adiposity on a total and percent basis in every area evaluated than did the static control group of men, the most profound difference in regional adiposity between the men and women was in the arm region. After 6 mo of training, the women were able to reduce their regional arm adiposity. However, the ending arm adiposity was still much greater than the arm adiposity of the male comparison group. This apparent gender-related difference in arm adiposity can be of functional consequence. Previous studies that have statistically controlled for regional muscle CSA (16) have reported that gender differences in strength and anaerobic power still persist, suggesting that factors other than muscle mass are responsible for gender differences in physical performance. One of these factors may be the relative amount of regional fat

Table 8. *Magnetic resonance imaging-assessed changes in thigh muscle morphology over 6 mo of periodized physical training*

Thigh Morphology	*Week 0*	*Week 24*
Whole thigh area, cm^2	249 ± 14	258 ± 15*
Lean area, cm^2	130 ± 6	137 ± 6*
%Lean	52.7 ± 7.2	55.9 ± 2.4*
Fat area, cm^2	114 ± 11	115 ± 12
%Fat	44.9 ± 2.2	43.7 ± 2.4
Individual muscles		
Rectus femoris, cm^2	8.2 ± 0.8	9.0 ± 0.8*
Vastus lateralis, cm^2	23.6 ± 1.1	24.9 ± 0.9
Vastus intermedius, cm^2	22.3 ± 1.8	22.9 ± 2.0
Vastus medialis, cm^2	10.7 ± 0.9	11.0 ± 0.8
Sartorius, cm^2	3.0 ± 0.2	3.0 ± 0.3
Biceps femoris shorthead, cm^2	1.3 ± 0.9	1.9 ± 0.5
Biceps femoris longhead, cm^2	9.9 ± 0.7	10.2 ± 0.7
Semitendinosis, cm^2	7.3 ± 0.4	7.6 ± 0.6
Semimembranosus, cm^2	5.5 ± 0.7	7.4 ± 1.6
Adductor group, cm^2	28.6 ± 1.5	29.2 ± 3.2
Gracilus, cm^2	3.9 ± 0.4	4.0 ± 0.4
Femur, cm^2	5.5 ± 0.2	5.5 ± 0.2

Values are means ± SD. *Significant change from before the beginning of the study (pre) to after the conclusion of 24 wk of training (post), $P \leq 0.05$.

Table 9. *Correlation between dual-energy X-ray absorptiometry-assessed and magnetic resonance imaging-assessed values for leg/thigh variables*

Variable	Correlation
Lean tissue	
Pre	0.84
Post	0.83
%	0.88
Fat tissue	
Pre	0.81
Post	0.92
%	0.72

Values are means ± SD. All values had significant correlation ($P \leq 0.05$).

mass. Excess noncontractile tissue (i.e., fat) in a particular region must still be displaced during limb movement. Higher amounts of fat tissue in women can impede acceleration and velocity in certain movements, thus retarding explosive power-type motions, and this influence is independent of muscle mass quantity. Thus, although the women in the present study did not experience increases in arm soft tissue lean mass, the significant and striking loss in fat mass of the arm area induced beneficial alterations in arm tissue composition (i.e., increased relative muscularity of the arm). This training-induced change could serve to augment movement-oriented physical performance (i.e., repetitive lifting ability in physically demanding tasks) (7, 17).

The increase in whole body soft tissue lean mass was not remarkable. It is important to note, however, that the intent of the training program was the improvement of women's military physical performance (e.g., lifting and load carriage) and not physical appearance or muscle hypertrophy per se. As such, a movement-oriented rather than a body part approach was emphasized. An emphasis on complex, multijoint exercises has been postulated to delay hypertrophic responses of the neuromuscular system due to prolonged neural adaptations (4). These putative neural adaptations to strength training are well known and include motor unit recruitment and synchronization, firing frequency, and altered agonist-antagonist activation patterns. Alternatively, because this study did not control for dietary intake, the small increase in soft tissue lean mass could be due to a lack of sufficient energy intake required to drive muscle growth in all regions of the body.

The whole body increase in soft tissue lean mass was mainly attributed to increases in soft tissue lean mass of the leg region, which was 5.5%, as determined by DEXA, in all 31 subjects and was 5.4% by MRI in the subset of 11 women. In contrast, no increases in soft tissue lean mass of the arms or trunk were observed. The differential hypertophy of the leg region over the arm and trunk regions can be attributed to specific stresses placed by the training program. The main purpose of the training program was specifically to improve women's lifting and load-carriage ability. In the design of the program, an emphasis was placed on structural and functional multijoint exercises. As such, isolation-type single-joint exercises were not selected. This fact may explain the lack of muscle hypertrophy of the arm region, because the muscles of this region were not isolated or specifically targeted. More puzzling was the lack of hypertrophy from the trunk region. Many of the exercises did, in fact, incorporate muscles located within this region. The muscles of this area are predominantly type I postural muscles, which, in women, are known to be larger than type II fibers and to undergo minimal hypertrophy (26). It is possible that the loading of the training was not heavy enough to recruit and activate type II motor units in the trunk area, thereby hindering the potential for significant fiber hypertrophy.

The findings in the present study are in contrast to those of Chilibeck et al. (4), who reported significant increases in DEXA-assessed lean mass of the arms, but not of the legs or trunk, after only 14 wk of resistance training. These disparate findings can be partially explained by close examination of the specific exercises performed in each program design. The study of Chilibeck et al. utilized arm curls and triceps extension, whereas the present study did not employ arm isolation exercises until *week 20* of the 24-wk program. Despite the lack of arm hypertrophy for the women in this study, one-repetition-maximum strength measurements involving large contributions from the upper body musculature significantly and dramatically increased (7). Kraemer et al. (8) recently reported mean increases of ~20% in MRI-assessed upper arm musculature after upper body resistance training in women. Thus, when adequately targeted and isolated, women can show impressive hypertrophy of the upper body musculature.

Bone mineral content remained unchanged in all areas evaluated after the training program. This finding is consistent with a report by Chilibeck et al. (3) in which it was reported that 20 wk of resistance training did not increase DEXA-measured bone mineral content and bone density in a whole body measurement or in any body region. Lohman et al. (10) also failed to find increases in total body bone mineral density after 18 mo of resistance training. However, these authors (10) did report small but significant regional increases in lumbar spine bone mineral density after 5 mo and in femur trochanter bone mineral density after 12 mo of resistance training. These results, taken together, suggest that localized changes in bone mineral content are observed before appreciable changes in whole body bone mineral content.

Few studies have made simultaneous DEXA and MRI measurements of limb composition before and after physical training intervention. Our data suggest that the two methods show good agreement, because both leg and thigh lean and fat soft tissue measurements were correlated both pretraining and posttraining. The percent changes in lean and fat soft tissue were also correlated. On a percent basis, the MRI gave higher percent fat values than did the DEXA values. The higher value for percent fat from MRI may be explained by the fact that the MRI estimates were for a single 1-cm scan of the midthigh, whereas the DEXA estimates were for the entire leg. Obviously, the portion of the leg below the midthigh, which included the calf, had less adiposity than did the midddle and upper area of the thigh. Tothill et al. (22) also used both MRI and DEXA to estimate total and regional fat in 13 premenopausal women. They reported that results from the two methods were highly correlated (r values up to 0.99) but displayed poor agreement, with DEXA readings yielding much higher values for total percent body fat. The authors did appropriately point out that, unlike DEXA, MRI measurements did not detect non-adipose-tissue fat. Furthermore, there are several potential limitations of DEXA technology. DEXA assesses three main tissue components: bone mineral, fat tissue, and lean tissue, but it only employs two photon energies and subsequent equations to separate the components (23, 24). Hence, it is possible that training can induce tissue changes that may impact underlying assumptions for X-ray attenuation coefficients. Future studies should explore whether training-induced changes in body morphology (i.e., relative distributions of regional tissue) also alter the assumed attenuation coefficients of different tissues.

Training altered the distribution of fat and soft tissue lean mass among the women, and this change impacted the differences between genders. Compared with men, women had a lower percentage of their total soft tissue mass distributed to the arms, both before and after training. The lower amount (on a total and relative basis) of muscle mass located in the arm area for women than for men could explain, in part, the gender variation in upper body strength and power. Women, however, had a higher percentage of their total soft tissue lean mass distributed in their trunk, both before and after training. Before training, women had relative fat in the legs similar to that of men. After training, women had relative fat in the legs greater than that of men. Although the underlying mechanisms responsible for gender differences in body morphology is undoubtedly multifactorial (e.g., hormonal, dietary, genetic), this study demonstrated that the direction of these differences between men and women can be influenced by training.

In summary, the training program used in this study proved effective in eliciting differential changes in regional morphology. Overall, significant increases in soft tissue lean mass and decreases in fat mass were observed. DEXA-assessed changes in leg fat and lean mass corresponded well to MRI-assessed changes in a subset of 11 women. This study represents one of the few attempts to document concomitant upper body, lower body, and truncal adaptations in soft tissue fat, lean mass, and bone mineral content in response to extended exercise training. The findings of this study extend current knowledge of regional body tissue plasticity and demonstrate differential regional adaptations. Meaningful information can be obtained from consideration of regional body composition changes rather than of whole body changes alone.

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